Pseudohypertension and the Measurement of Blood Pressure

Willem Jan W. Bos, Jeroen van Goudoever, Karel H. Wesseling, Gerard A.P.J.M. Rongen, Gerard Hoedemaker, Jacques W.M. Lenders, and Gert A. van Montfrans

Riva-Rocci Korotkoff (RRK) blood pressure measurements may overestimate the intra-arterial pressure (IAP) in individual patients. To study pseudohypertension, defined as an overestimation larger than 10 mm Hg, we compared RRK and IAP measurements in 76 patients. These patients were considered to be at risk for pseudohypertension because of high age, hypertension, or vascular disease. RRK measurements underestimated simultaneously measured systolic IAP values by 6.0 ±6.5 (mean±SD) mm Hg, whereas simultaneous diastolic RRK readings overestimated the IAP by 1.9±5.6 mm Hg. Diastolic overestimation increased slightly with age. Vascular rigidity, as measured by counterpressure plethysmography, did not correlate with these errors. Systolic and diastolic pseudohypertension was observed in two and five patients, respectively. Pseudohypertension was only present in the group in which IAP was measured in the aorta. However, the number of patients with systolic and diastolic pseudohypertension could be increased to three and seven by using the average infra-arterial systolic and diastolic pressure during an RRK measurement or to six and 11 by using the IAP during a control period just before an RRK measurement rather than the IAP at the moment of appearance or disappearance of the Korotkoff sounds. The widely diverging prevalence of pseudohypertension described in the literature might be explained because of such different comparison techniques. (Hypertension 1992;20:26-31)

KEY WORDS • age factors • blood pressure, measurement of • pseudohypertension • essential hypertension

Riva-Rocci/Korotkoff (RRK) measurements of arterial blood pressure have been performed for almost a century. In the 1940s and 1950s, they were shown to agree reasonably well with intra-arterial pressure (IAP) measurements. Subsequently, their value in predicting cardiovascular disease, and therefore their value in the clinical management of hypertension, has been well established. However, many factors may cause erroneous RRK measurements. Concerns have, for example, been raised about the reliability of RRK measurements in patients with Mönckeberg's medial calcification, in whom pseudohypertension, defined as any RRK-IAP difference exceeding 10 mm Hg, may occur because the brachial artery cannot be compressed. However, pseudohypertension has not only been described in patients with extreme calcifications of the brachial artery, but also in varying numbers in healthy, hypertensive, and elderly populations.

Methods

Patients

Comparison with IAP, measured in the aorta, was performed in 19 patients (group A) undergoing coronary angiography because of stage III or IV (New York Heart Association) anginal complaints. This group included four patients with peripheral vascular disease. The measurement protocol was executed immediately after successful and uncomplicated coronary angiography. Patients with valvular disease or arrhythmias were excluded. Comparison with IAP recorded in the brachial artery was performed in three groups of patients. Group B consisted of 13 hypertensive patients with therapy-resistant hypertension (defined as the need to use two or more antihypertensive drugs) and vascular disease, in whom IAP measurements exceeded the IAP by more than 10 mm Hg. Therefore, in this report we focus on possible reasons for this finding.

We set out to study etiology and detectability of pseudohypertension. Therefore, we performed our measurements in patients with a relatively high probability of pseudohypertension due to hypertension, vascular damage, or old age. However, we observed only a limited number of patients in whom the RRK measurements exceeded the IAP by more than 10 mm Hg. Therefore, in this report we focus on possible reasons for this finding.

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Intra-arterial Blood Pressure Determinations

In group A, we used a 7F pigtail catheter, introduced via the femoral artery with the tip placed in the aortic arch. In the other groups, a short Teflon cannula was inserted in the brachial artery of the nondominant arm. The cannula was connected with rigid tubing to a transducer (model HP 1290A, Hewlett Packard, Palo Alto, Calif.) in groups B and D, a Gould Statham P 23 XL in group A, and a model DTX, (Statham Division, Gould Inc., Oxnard, Calif.) in group C and was positioned at heart level. To obtain an adequate dynamic response we used a damping device (Rose, Gould) in group A. Natural frequencies and damping coefficients of the fluid-filled systems were approximately 18 and 0.3±3.8 mm Hg for systolic readings, and 3.0±2.7, 1.0±2.4, and 0.9±2.6 mm Hg for diastolic readings. Since the IAP in group A was not measured in the opposite arm, left-to-right differences were not measured in this group. Basic characteristics, including age, sex, arm circumference, and blood pressure, of these groups are mentioned in Table 1. The protocol was approved by the institutional review committee of the hospital. All participants gave informed consent. For clinical reasons, medication was not interrupted in patients receiving antihypertensive therapy.

Indirect Blood Pressure Measurements

In each patient we performed two supine RRK measurements on the dominant arm. We used a 38×14 cm cuff, which has been shown to give accurate readings even in patients with large arm circumferences, a constant cuff deflation rate of 2.5 mm Hg/sec, and a recently calibrated normal mercury sphygmomanometer in all groups, except group D, in which the Hawksley Random Zero Manometer was used. At the detection of Korotkoff phase I (KI) and Korotkoff phase V (KV) a marker was recorded. Cuff pressure was measured continuously (Motorola MPX 2050, Phoenix, Ariz.) and was recorded together with IAP on stripchart (TA 4000, Gould Inc., Cleveland, Ohio) and on tape (HP 3964A, Hewlett Packard). The measurements were performed by either one of two well-trained observers, who had both recently passed audiographic testing. The two measurements were separated by at least 1 minute.

Data Analysis

Intra-arterial signals were A/D converted at a sampling rate of 100 Hz, and beat-to-beat values of systolic, mean, and diastolic pressures were computed for the IAP, using FAST system programs. A single measurement is shown in Figure 1. Since different comparison techniques have been used in the literature, three different values of the IAP were used for the comparison with RRK measurements: 1) the one beat systolic and diastolic IAP value at KI and KV, respectively, 2) the average IAP during the measurement period, and 3) the average IAP during a 30-second control period immediately preceding the RRK measurement (Figure 1).

Table 1. Basic Characteristics of the Four Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Med</th>
<th>Mean</th>
<th>Range</th>
<th>Gender</th>
<th>Arm circumference (cm)</th>
<th>IAP during control period (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
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<td></td>
<td></td>
<td>Systolic Mean</td>
<td>Range</td>
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<tr>
<td>A</td>
<td>19</td>
<td>18</td>
<td>63</td>
<td>34-89</td>
<td>M</td>
<td>31</td>
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<tr>
<td>B</td>
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<td>13</td>
<td>66</td>
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<td>F</td>
<td>29</td>
<td>26-33</td>
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<tr>
<td>C</td>
<td>15</td>
<td>0</td>
<td>76</td>
<td>71-83</td>
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<td>28</td>
<td>25-31</td>
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<tr>
<td>D</td>
<td>29</td>
<td>26</td>
<td>51</td>
<td>34-65</td>
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</table>

Med, number of patients taking antihypertensive medication; IAP, intra-arterial pressure.

Figure 1. Representative recording shows intra-arterial and cuff pressure before and during a Riva-Rocci/Korotkoff (RRK) measurement. A marker was placed on the cuff pressure at the instant of Korotkoff phase I (KI) and phase V (KV). The control and measurement period used for comparison are indicated. Note that KI occurs at a moment when the varying systolic intra-arterial pressure (IAP) is relatively high. In this example the RRK measurement underestimates systolic as well as diastolic IAP.
Estimation of Vascular Rigidity

It has been suggested that pseudohypertension could result from increased vascular rigidity.32 In groups A, B, and C we determined separately in another session the volume changes beneath a slowly deflating cuff around the forearm, using electrical impedance plethysmography, as described by Gizdulich and Wesseling.32 Arterial transmural pressure was calculated by subtracting finger mean arterial pressure measured contralaterally by the Finapres27 from the pressure in the cuff placed over the sensing electrodes of the plethysmograph.32 With this method arterial characteristics can be studied over a wide range of transmural pressures. We used the slope of the steepest part of the pressure-volume curve around zero transmural pressure as an indicator for vascular rigidity. Data are derived from the average of three curves in each patient, and expressed in millimeters of mercury per milliliter per 100 milliliters of tissue volume.32

Statistics

RRK versus IAP comparisons are based on the average of the two RRK measurements in each patient. The four groups were compared with the Kruskal-Wallis one-way analysis of variance by ranks. Differences between RRK and IAP measurements, as well as differences between the three comparison methods, were tested with Wilcoxon’s matched-pairs signed-rank test. Correlations were calculated using Spearman’s rank correlation analysis.

Results

IAP values obtained during the control period are presented in Table 1. In all groups systolic RRK readings underestimated IAP at KI, whereas diastolic RRK readings mainly overestimated the IAP at KV (Figure 2 and Table 2). Both systolic and diastolic RRK-IAP differences were larger than 10 mm Hg in one patient, whereas systolic or diastolic differences were larger than 10 mm Hg in one and four additional patients, respectively, in group A. In Table 2 RRK-IAP differences are presented, as well as the number of cases in which the difference is larger than 10 mm Hg, for the three ways of comparison. Since the differences between different comparison methods did not differ statistically among the four groups (Kruskal-Wallis), further evaluation was performed on the pooled results. When the average IAP during the measurement period was used, rather than the IAP at KI and KV, the underestimation of the systolic IAP decreased (p<0.01), whereas the overestimation of the diastolic IAP was similar. In comparison with both other methods, the systolic underestimation further decreased when the IAP during the 30-second control period was used (p<0.01), whereas the diastolic overestimation increased (p<0.01). The decreases in systolic underestimation were based on the fact that the systolic IAP at KI was 2.9±3.9 (p<0.01) and 5.1±5.6 (p<0.01) mm Hg higher than the average systolic IAP during measurement and control periods, respectively. Differences between the diastolic IAP at KV and during the measurement and control periods were 0.2±2.2 mm Hg (NS) and 1.5±2.6 mm Hg (p<0.01), respectively. Correlation analysis was performed on the pooled results of groups B, C, and D, since the RRK-IAP differences in group A differed from those in the other groups (see Figure 2). The diastolic RRK-IAP difference increased with age (r=0.28, p<0.05). No such relation could be observed for systolic differences. Neither systolic nor diastolic RRK-IAP differences correlated with arm circumference, or systolic and diastolic blood pressures (mean of RRK and IAP).

In the impedance plethysmography the maximal slope of the pressure–volume curve was 25.2±12.0, 30.0±11.7, and 27.4±11.9 mm Hg/ml/100 ml tissue volume in groups A, B, and C (NS). No significant correlation was observed between the maximal slope and systolic or diastolic RRK-IAP differences.

Discussion

Frequently we have been alerted that pseudohypertension might cause overdiagnosis of hypertension in the elderly.1,12,16,23,24 Yet data on its prevalence widely diverge.1,2,9-25 The present study was not set up to study the prevalence in any particular population, but rather to gain insight in etiology and diagnosis of the phenomenon. We therefore studied several populations considered to be at increased risk for this condition because of hypertension, vascular damage, and/or high age.1,16,20,21,23 We observed two patients in whom the systolic RRK-IAP difference was more than 10 mm Hg and five patients in whom diastolic differences were, albeit marginally, higher than 10 mm Hg. The variation in the prevalence of pseudohypertension in the present study, as well as in the literature, prompted us to take a
closer look at the exact ways in which both blood pressure measurements have been compared. Therefore, we reviewed studies in which RRK and IAP have been compared and from which average RRK-IAP differences, as well as the number of patients with pseudohypertension, could be derived.1,2,8-25 There is a wide variation, not only in results, but also in populations studied.1-2,8-13 Since different patient selection criteria only explain part of the differences in results, we will discuss our own results with those in the literature in terms of the measurement techniques used.

When, as in pseudohypertension, RRK measurements overestimate the IAP, this can either be caused by an IAP measurement that is too low or by an RRK measurement that is too high. There are several factors that interfere with a correct IAP measurement:

1) Measurement site. The IAP used for comparison studies has been measured at different sites in the arterial system. The IAP has been measured in the radial,1,2,8,9,13,15,16,18,22,23 the brachial (References 1, 2, 10, 12-15, 17, 19, 21, and the present study), and the femoral arteries24,25 as well as in the aorta (Reference 20 and the present study). However, due to peripheral reflections the pulse pressure increases on its way from the aorta to the periphery,36-37 leading to an increased systolic IAP in the brachial and radial artery. Therefore, the more central the intra-arterial measurement site, the higher the expected number of patients with pseudohypertension. Indeed, systolic RRK-IAP differences were highest in group A. Since reflections do not influence the diastolic pressure, the higher diastolic RRK-IAP differences in group A cannot be explained by the use of different measurement sites. However, since the IAP was lowest in group A, the higher RRK-IAP differences are in agreement with the observation that diastolic RRK readings also overestimate the IAP more when the blood pressure is low.3,23

2) Moment of comparison. We decided to use the IAP at KI and KV as the reference against which RRK measurements have also been compared with the average IAP during any other12-24 or during any not specifically mentioned interval during the RRK measurement1-10-14-18-20-25 or with the average IAP of some control period before or after the RRK measurement.1,2,8,9,13,15,16,21,23 However, the present study shows that the IAP values obtained in these ways are not necessarily identical. In our study, the systolic IAP at KI was higher than the average systolic IAP during the measurement, most likely due to the fact that the first Korotkoff sounds are more likely to occur near a maximum of a fluctuating IAP.38 Furthermore, systolic and diastolic IAP may be slightly higher during the measurement than in the control period.39-40 In our present study, the shift in RRK-IAP differences caused by these different ways of comparison resulted in a variation in the number of patients with pseudohypertension (from two to six out of 76 for systolic values, and from one to four out of 19 for diastolic values). This effect should be kept in mind for most reported studies.

3) Number of comparisons. The number of measurements taken, which is then averaged in individual patients, varied from 11,2,16 to 10.23 However, when a large number of RRK-IAP comparisons are averaged in each patient, the average RRK-IAP differences will remain

| TABLE 2. Differences for all Groups Between Riva-Rocci/Korotkoff and Intra-arterial Pressure Using Three Values of the Intra-arterial Measurement |
|----------------------------------|----------|-----------------|-----------------|-----------------|
| IAP used for comparison          | Group    | Systolic         | Diastolic        |                       |
|                                  |          | Mean ± SD        | Mean ± SD        | n > 10 mm Hg        |
|                                  |          |                  |                  |                  |
| KI/KV                            | A        | -0.5 ± 7.2       | 5.9 ± 4.4*       | 5                 |
|                                  | B        | -11.5 ± 5.6*     | -2.5 ± 6.1       | 0                 |
|                                  | C        | -6.3 ± 4.3*      | 3.4 ± 4.3*       | 0                 |
|                                  | D        | -7.0 ± 4.5*      | 0.5 ± 4.4        | 0                 |
|                                  | Total    | -6.0 ± 6.5*      | 1.9 ± 5.6*       | 5                 |
| Measurement                      | A        | 2.7 ± 6.4        | 6.3 ± 4.9*       | 5                 |
|                                  | B        | -8.5 ± 6.2*      | -1.4 ± 6.7       | 0                 |
|                                  | C        | -3.8 ± 4.9*      | 3.7 ± 5.0*       | 1                 |
|                                  | D        | -4.2 ± 4.6*      | 0.0 ± 5.6        | 1                 |
|                                  | Total    | -3.1 ± 6.6*      | 2.1 ± 6.3*       | 7                 |
| Control                          | A        | 6.1 ± 6.8*       | 7.9 ± 4.8*       | 7                 |
|                                  | B        | -6.9 ± 7.8*      | 0.0 ± 6.9        | 0                 |
|                                  | C        | -1.6 ± 4.9       | 5.5 ± 5.2*       | 3                 |
|                                  | D        | -2.6 ± 5.6*      | 0.9 ± 5.6        | 1                 |
|                                  | Total    | -1.0 ± 7.6*      | 3.4 ± 6.5*       | 11                |

IAP, intra-arterial pressure. KI and KV, one-beat systolic and diastolic value of intra-arterial pressure at the moment of Korotkoff phase I and V, respectively.

*p < 0.05 between Riva-Rocci/Korotkoff and IAP.

†p < 0.05 between different comparison methods (KI/KV vs. measurement and KI/KV vs. control).

‡p < 0.05 between different comparison methods (measurement vs. control).
at the same level, but the scatter of the RRK-IAP difference will become smaller. Thus, the number of patients with pseudohypertension can be influenced by the number of RRK versus IAP comparisons averaged in each patient. In the present study we used the average of two measurements.

4) Dynamic characteristics of the measurement system. In all cited studies in which RRK and IAP are compared as well as in our own study, fluid-filled catheter manometer systems were used. The systolic IAP can easily be underestimated when the system is overdamped or when the natural frequency is too low. However, in most studies in which dynamic characteristics were mentioned, the system was slightly underdamped and potentially overshooting, as was the case in our own study. This may result in underestimation of IAP values by RRK measurements.

Factors relevant to this discussion that may cause RRK readings to be too high are:

1) RRK technique. RRK measurements can be flawed by many simple technical "errors." One factor resulting in overestimation of diastolic pressures is the previously recommended use of Korotkoff phase IV rather than KV.

RRK readings will also overestimate the IAP when the cuff used is too small. At first the small 10 x 14 cm cuff used by Spence et al.46 and Finnegan et al.47 might explain the high prevalence in these studies; however, in reality an adult-size cuff was used (JD Spence, personal communication, 1991). Even cuffs sized 12-13 x 22-24 cm4.4.4.14.15.18.19.19.19.19 have been shown to lead to an overestimation of several millimeters of mercury.28

Of concern are reports in which the Hawksley Random Zero Manometer has been shown to underestimate RRK readings with a normal sphygmomanometer by a varying number of millimeters of mercury.15.41.42.43 This might influence our own results from group D as well as those of several other studies.8.24.28 The systolic underestimation has been reported to be 0.9, 3.3, and 3.8 mm Hg, whereas diastolic underestimations of 1.8, 2.7, and 7.5 mm Hg have been reported (studies reported in References 41, 42, and 43, respectively). Thus, that number of patients showing systolic pseudohypertension would not be affected by correction for the use of the Random Zero Sphygmomanometer. However, the number of patients with diastolic pseudohypertension might have been underestimated by from one to nine patients. After publication of the above mentioned reports, we decided not to use this device in the more recently performed parts (groups A, B, and C) of our study.

2) Vascular rigidity. In 1881 von Basch suggested that vascular rigidity might interfere with indirect blood pressure readings. Vascular rigidity increases the cuff pressure needed to occlude an artery and could also cause weakened Korotkoff sounds, resulting in higher diastolic RRK readings. It is easy to imagine how these factors lead to high levels of pseudohypertension in those rare patients with completely calcified arteries.11.14.46 However, results of studies in which different populations are compared1.10.16.18.20.21 widely diverge, and it is not clear whether increased vascular rigidity in old age, hypertension, and atherosclerosis could influence RRK readings. In the present study, diastolic differences did indeed increase slightly with age. However, no correlation could be observed between blood pressure levels and RRK-IAP differences. Furthermore, a relation between vascular rigidity and RRK-IAP differences has both been described,6.20 and denied.10 Using a different measure for vascular rigidity,22 we could not confirm such a correlation in the present study. However, we cannot exclude that in some patients, the vascular rigidity has been influenced by the use of vasoactive drugs such as nitrates, calcium entry, and angiotensin converting enzyme inhibitors, which have been shown to increase the compliance of the brachial artery in hypertensive patients50 and which were continued during the present study.

Most of the factors mentioned above influence systolic RRK versus IAP comparisons. Although diastolic comparisons are less affected, the prevalence of diastolic pseudohypertension is also easily influenced since the average diastolic RRK-IAP difference normally is positive already. It will be clear that almost all previously described studies are affected by one or more of the factors discussed in this report. Therefore, we conclude that the prevalence of pseudohypertension may have been overestimated in the past due to the way in which the blood pressure has been measured and compared. In elderly, hypertensive and atherosclerotic populations we found a modest degree of pseudohypertension that was not related to vascular rigidity.

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